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Form Approved
OMB No 0704-0188

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1 AGENCY USE ONLY (Leave Blank)		2 REPORT DATE March 1993		3 REPORT TYPE AND DATE COVERED Professional paper	
4 TITLE AND SUBTITLE APPLICATION OF THE SONAR EQUATION TO DOLPHINS ECHOLOCATION				5 FUNDING NUMBERS PR: MMB2 PE: 0602435N WU: DN688674	
6 AUTHOR(S) W. W. L. Au					
7 PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Command, Control and Ocean Surveillance Center (NCCOSC) RDT&E Division San Diego, CA 92152-5001				8 PERFORMING ORGANIZATION REPORT NUMBER	
9 SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Command, Control and Ocean Surveillance Center (NCCOSC) RDT&E Division Block Programs San Diego, CA 92152-5001				10 SPONSORING/MONITORING AGENCY REPORT NUMBER	
11 SUPPLEMENTARY NOTES					
12a DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b DISTRIBUTION CODE	
13 ABSTRACT (Maximum 200 words) The target detection capability of the Atlantic bottlenose dolphin (<i>Tursiops truncatus</i>) in the open waters of Kaneohe Bay, Oahu, Hawaii will be discussed using the noise-limited form of the sonar equation. In Kaneohe Bay, <i>Tursiops</i> typically emit short duration transient-like broadband echolocation signals with peak frequencies between 110-130 kHz in (Au, 1980). Therefore the generalized or transient form of the sonar equation based on energy flux density instead of intensity must be used (Urick, 1983).					
<div style="text-align: center;"> </div> <div style="text-align: right;"> 93-13612 </div> <p>Published in <i>Proceedings 14th International Congress on Acoustics</i>, September, 1992.</p>					
14 SUBJECT TERMS marine biosystems marine biology marine animal				15 NUMBER OF PAGES	
93 6 16 04 1				16 PRICE CODE	
17 SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18 SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19 SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20 LIMITATION OF ABSTRACT SAME AS REPORT		

UNCLASSIFIED

21a NAME OF RESPONSIBLE INDIVIDUAL W. W. L. Au	21b TELEPHONE (Include Area Code) 808-257-1647	21c OFFICE SYMBOL Code 512
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DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
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Availability Codes	
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APPLICATION OF THE SONAR EQUATION TO DOLPHIN ECHOLOCATION

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The target detection capability of the Atlantic bottlenose dolphin (*Tursiops truncatus*) in the open waters of Kaneohe Bay, Oahu, Hawaii will be discussed using the noise-limited form of the sonar equation. In Kaneohe Bay, *Tursiops* typically emit short duration transient-like broadband echolocation signals with peak frequencies between 110-130 kHz in (Au, 1980). Therefore the generalized or transient form of the sonar equation based on energy flux density instead of intensity must be used (Urlick, 1983). An example of a *Tursiops* echolocation signal and its frequency spectrum is shown in Fig. 1. The peak-to-peak source level is shown on the oscilloscope display.

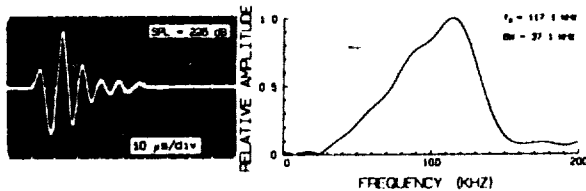


Fig. 1. An example of an echolocation signal of *Tursiops truncatus* measured in Kaneohe Bay.

1. GENERALIZED SONAR EQUATION: NOISE-LIMITED FORM

The generalized form of the noise-limited sonar equation applicable to a dolphin can be expressed as (Urlick, 1983)

$$DT_e = SE - 2 TL + TS_e - (NL - DI) \quad (1)$$

The detection threshold, DT_e corresponds to the energy-to-noise ratio used in human psychophysics and is equal to $10 \log (E_e/N_e)$, where E_e is the echo energy flux density and N_e is the noise spectral density level. SE is the source energy flux density, TL is the transmission loss, TS_e is the target strength based on the ratio of the energy in the echo and incident energy, NL is the ambient noise density, and DI is the receiving directivity index.

In order to use Eq. 1, the target detection capability of the dolphin must be measured along with other parameters associated with the animal's sonar and the environment. Murchison (1980) performed a maximum range detection experiment with two *Tursiops*, using a 2.54-cm diam. solid steel sphere and a 7.62-cm diam. stainless steel water-filled sphere as targets. The composite 50% correct detection threshold were at ranges of 72 and 77 m for the 2.54-cm and 7.62-cm spheres, respectively. However, the dolphins performance with the 7.62-cm sphere was affected by reverberation from a bottom ridge located at a range of 73 m.

Au and Snyder (1980) remeasured the maximum detection range in a different part of Kaneohe Bay using one of the same dolphins (Sven) and a 7.62-cm diam. sphere. Sven's target detection performances for the 2.54-cm sphere (Murchison, 1980) and the 7.62-cm sphere (Au and Snyder, 1980) are plotted in Fig. 2 as a function of range. The 50% correct detection threshold for the 7.62-cm sphere occurred at 113 m, a considerably longer range than the 76.6 m measured by Murchison (1980).

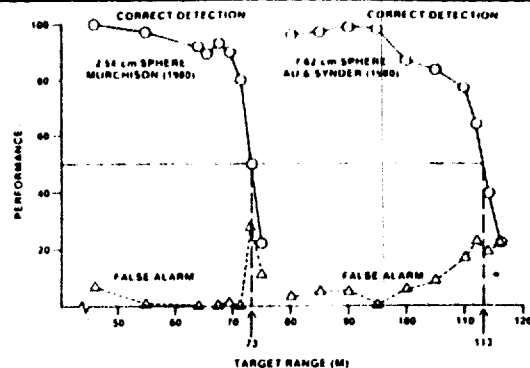


Fig. 2. Target detection performance a *Tursiops truncatus* as a function of range for two spherical targets (from Murchison, 1980; Au and Snyder, 1980).

11. APPLYING THE SONAR EQUATION

The parameters in the sonar equation (Eq. 1) will now be discussed according to the order they appear in the equation. The first term has to do with the signals used by dolphins. Sonar signals are projected in a beam directed forward of the animal. The composite transmit beam pattern from three dolphins in the vertical and horizontal planes (Au et al., 1978; Au, 1980; Au et al., 1986) are shown in Fig. 3. The 3-dB beamwidth in both planes have similar values, approximately 10° .

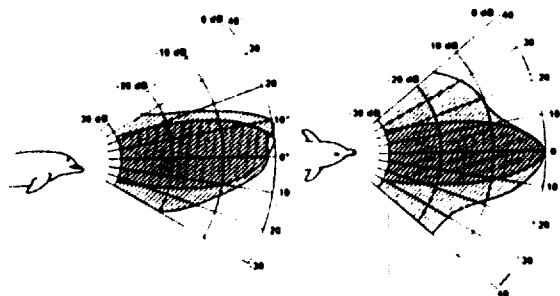


Fig. 3. Transmit (inner curves) and receive (for a frequency of 120 kHz; outer curves) beam patterns for *Tursiops* in the horizontal and vertical planes.

The sonar signals of the dolphin used to obtain the data shown in Fig. 2 were measured in the study of Au et al. (1974) for target ranges of 59 to 77 m. However, dolphins can vary the amplitude of their sonar signals over a 20 dB range during a single sonar search, making it difficult to accurately estimate the detection threshold. Au and Pawloski (1989) performed an experiment to determine the relationship of the detection threshold based on the maximum source energy flux density per trial to a more accurate estimate of the detection threshold using an electronic phantom target which played back simulated echoes at a constant amplitude regardless of the amplitude of the dolphin's emitted signal. They found that the detection threshold, E_e/N_e , was 2.9 dB lower than the detection threshold based on the maximum source level. Therefore, an accurate estimate of the dolphin detection threshold can be obtained by using the maximum source energy flux density and subtracting 2.9 dB from it. Au (1980) also showed that the energy flux density is approxi-